CHAPTER 8

Approaches to Quality Assurance and Information Management for Regional Ecological Monitoring Programs

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When evaluating the effectiveness of regional ecosystem initiatives, ecological monitoring data from many different sources must be combined. Several different organizations may collect and evaluate information essential to the overall success of the monitoring program. These organizations may also have archived data of potential value to regional assessments. The manner in which ecological monitoring data are collected, summarized, interpreted, and archived has a significant effect on the data's long-term utility. This can best be explained by providing two recent examples.

Example 1: An All Too Common Past

Scientists involved in the development of a regional ecological monitoring program interviewed agency staff regarding the availability of historical forest inventory data. They were excited to learn that three extensive regional timber inventories had been conducted in 1968, 1978, and 1988 with the specific measurements they needed to address their monitoring questions. These data had been collected at a significant expense to address the needs of a ten-year planning cycle for timber management.

Upon further examination, however, they learned that none of these data were readily accessible. The first two inventory results had at one time been available on a mainframe computer but were now available only by reviewing the original reports. The most recent survey was available in electronic format, but the format was that of a program no longer supported by the agency. All data were stored on outmoded media and would be difficult to extract due to changes in computer hardware. A few manuals were available to describe how the data were collected, but no information was available on the quality of the data nor the quality-control procedures used to ensure comparability in the data between field crews. The individual most knowledgeable about the surveys had recently retired, making the use of the data even more difficult. The end result was that these scientists determined that the considerable effort it would take to make these data available rendered them useless.

Example 2: A Possible Future

Two soil scientists involved in the development of a national forest monitoring program were asked to determine if the monitoring program could detect a 2 percent change per year in soil carbon at a regional scale. To answer this question, they decided to remeasure some forest plots that had been sampled eight years previously during a regional pilot study. As the original study had been funded by a regulatory agency that required quality assurance plans and documentation, the scientists were able to obtain detailed information about how soil samples had been collected, processed, and analyzed and the precision associated with each of these activities. The original database was still available as it had been maintained and updated periodically to new hardware and software systems. As a result, a successful remeasurement study could be undertaken.

Objectives of This Chapter

The problem faced by many regional ecosystem-monitoring programs is how to get from the all-too-common reality described in the first example to the possible future described in the second example. Unless steps are taken at the initiation of regional monitoring programs to address quality assurance (QA) and information management (IM), data that are collected today may have very little utility in the future.

The first objective of this chapter is to provide a conceptual basis for quality assurance and information management in ecological monitoring programs. The role of monitoring data in the adaptive management cycle will be described as well as the process for changing data into information and knowledge that might assist with natural resource management decisions. The goals of QA and IM systems will be reviewed and basic concepts presented. The second objective is to describe alternative approaches for structuring QA and IM systems in monitoring programs, and the final objective is to provide some suggestions on how to initiate QA and IM programs for regional ecosystem initiatives.

Conceptual Basis

When planning a regional ecosystem-monitoring program, it is helpful to consider alternative approaches one might take to the collection and management of data and information. The purpose of this section is to lay the groundwork for a discussion by reviewing how information flows in an adaptive ecosystem management cycle and what resource managers hope to achieve with the data collected in monitoring programs. Basic concepts regarding the management of ecological data will be discussed along with approaches to ensure that data collected are of the highest quality.

Information Flow in the Adaptive Ecosystem Management Cycle

In an adaptive ecosystem management cycle, a decision is implemented to achieve goals related to the ecosystem being managed. Monitoring of the ecosystem provides feedback to management regarding the effectiveness of management actions in achieving those goals. Based upon these results, new management decisions can then be implemented creating an adaptive cycle that, hopefully, improves itself over time.

For this cycle to work effectively, information must readily flow from the monitoring program to the decision makers. This process is depicted in figure 8-1. Field measurements must first be collated into a database. These data can then be summarized into information. Information, by itself, may not be of value to decision makers unless it is synthesized and interpreted along with other monitoring and research information into a better understanding and knowledge of how the ecosystem is responding to management actions. Based upon this knowledge, new decisions can then be made with the hope of improving management of ecosystem condition.

This process can be illustrated by the steps involved in developing a monitoring strategy for the Northwest Forest Plan (Palmer and Mulder 1999). In developing that plan, the authors considered this cycle and the steps that would need to be taken to have field measurements that are ultimately useful in the decision-making process. The danger, as the authors saw it, was that significant resources might be expended in the collection of data that ultimately were not used in the adaptive management process

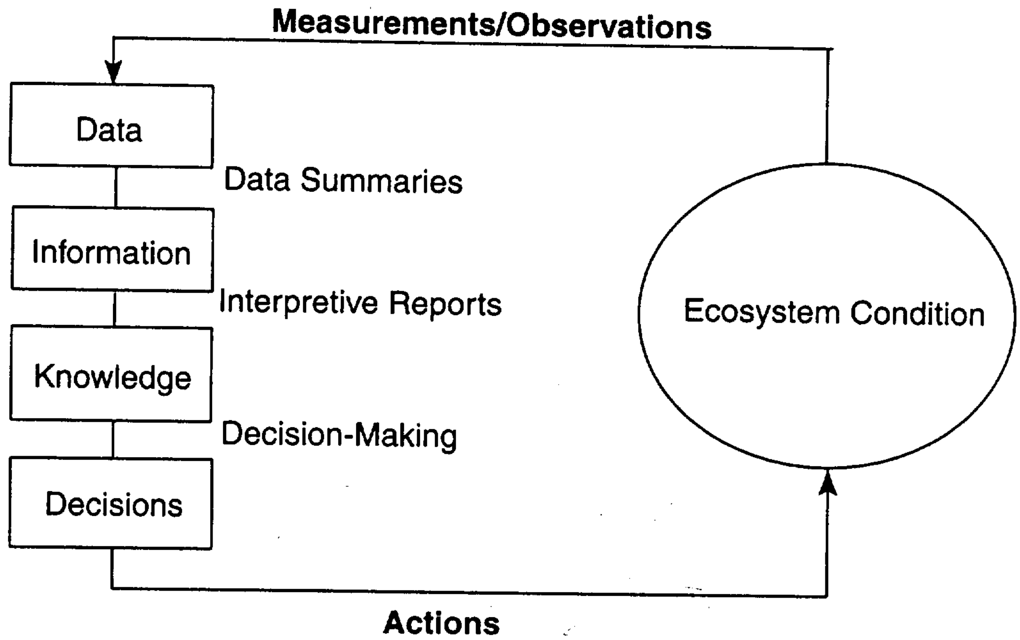

Figure 8-1. Flow of monitoring information in the adaptive management cycle.

due to information overload. As T. S. Eliot (1980) wrote, "Where is the wisdom we have lost in knowledge? Where is the knowledge we have lost in information?" One might add another line to this poem: Where is the information we have lost in data?

A primary recommendation made to management was that a reporting process be developed to summarize data into information through the preparation of annual data summaries (Palmer and Mulder 1999). These reports would be "preplanned" in terms of their format, content, and approach to data synthesis. The annual frequency of these reports would have the added benefit of encouraging the development of databases through the collation and checking of data in a timely manner. As a second step in the reporting process, the preparation of periodic interpretive reports was recommended to encourage the synthesis of information from the annual data summaries into a better understanding of ecosystem condition. In addition to evaluating monitoring data, the preparation of synthesis reports required an evaluation of other ongoing research activities, data from other monitoring programs, and the use of the latest modeling and statistical tools.

Data Management Goals of Natural Resource Managers

In addition to fostering the adaptive management cycle, land managers have other goals related to data management that should be considered when establishing a monitoring program. During a review of data management goals for a land management unit in the lower Colorado River basin (Landis and Palmer 2000), we learned that several objectives must be taken into consideration when developing a data management system. These objectives include permanence, accessibility, credibility, and accountability.

Ecological data can be lost, or lose significant value over time, unless care is taken to adequately document and maintain these data. This is a process called data entropy (Michener et al. 1997) and was described earlier in this chapter with the example of "an all-too-common past." The study of ecosystems often requires the analysis of long-term trends and relationships. These can only be undertaken if data management systems provide permanence to the data for at least several decades. Preventing data entropy must take into consideration both the gradual processes and the discrete events that can cause data loss. Gradual processes include the degradation of storage media, the obsolescence of storage technology, the destruction of data forms and notes, and the loss of specific facts from the memories of the investigators. Discrete events leading to data loss include changes in personnel (e.g., retirement, career changes, death), loss of computer records, loss of conceptual or computer models used to interpret data, or the loss of storage media through a catastrophic event.

A second requirement is that ecological data be readily accessible, preferably through the Internet. The synthesis of data into information and knowledge at regional scales frequently requires the participation of many individuals, often from different organizations. Unless the data are easily available, this participation is not likely to occur.

Users must also have access to information about data-collection methods and quality of data. Once they have ascertained that the data are credible, they can then proceed with the summarization and synthesis into useful information and knowledge. The information system must therefore provide documentation about the data through the development of appropriate metadata. Metadata may be defined as a higher level of information or instructions that describe the content, context, quality, structure, and accessibility of a data set (Michener et al. 1997). This information should also be available in a readily accessible manner and should include all the information needed to enable the long-term reuse of data sets by the original investigators as well as new uses by other scientists not involved in the original data-collection efforts.

An important trend from a resource manager's perspective is increasing accountability for the natural resources they are responsible for managing. To address this accountability, resource managers require ecological data and information that is legally and scientifically defensible. The quality assurance and information management systems supporting the acquisition, maintenance, and interpretation of these data must help foster such defensibility.

Quality-Assurance Concepts

An important goal of monitoring programs is to obtain data that are meaningful, representative, reliable, and comparable over space and time (Burton 1995; Mohnen 1996). Quality assurance refers to those activities undertaken during the planning, implementation, and assessment phases of a project to ensure that monitoring results meet these expectations (Taylor 1987). Regulatory agencies such as the Environmental Protection Agency and the Department of Energy require that a structured quality assurance program, as well as quality-assurance plans, be in place prior to data collection in monitoring programs. These requirements are detailed by the American National Standards Institute (ANSI 1995) and the basic elements are summarized in table 8-1. Definitions for some common quality-assurance terms are provided in table 8-2. A quality-assurance program is often documented in a quality-management plan that describes a system (Kulkarni and Bertoni 1996) of policies and procedures used to ensure that the monitoring data will be of the type and quality needed (Storey et al. 2000; EPA 2001b). The quality-management plan is used as a framework for quality-assurance activities during planning, data collection, and assessment phases of monitoring programs. These activities can include the preparation of detailed quality-assurance project plans

Table 8-1. Quality-assurance elements required by the American National Standard Institute (ANSI 1995) for environmental monitoring programs.

Quality-management elements	*Specific project elements*
Management and organization	Planning and scoping
Quality system and description	Design of data collection operations
Personnel qualification and training	Implementation of planned operations
Procurement of items and services	Assessment and response
Documents and records	Assessment and verification of data usability
Computer hardware and software	
Planning	
Implementation of work processes	
Assessment and response	
Quality improvement	

Table 8-2. Quality assurance terms and definitions (from EPA 2001a).

Term	*Definition*
Quality	The totality of features and characteristics of a product or service that bear on its ability to meet the stated or implied needs and expectations of the user.
Quality assurance (QA)	An integrated system of management activities involving planning, implementation, documentation, assessment, reporting, and quality improvement to ensure that a process, item, or service is of the type and quality needed and expected by the customer.
Quality assurance project plan	A document describing in comprehensive detail the necessary quality assurance, quality control, and other technical activities that must be implemented to ensure that the results of the work performed will satisfy the stated performance criteria.
Quality control (QC)	The overall system of technical activities that measures the attributes and performance of a process, item, or service against defined standards to verify that they meet the stated requirements established by the customer; operational techniques and activities that are used to fulfill requirements for quality.
Quality management	That aspect of the overall management system of the organization that determines and implements the quality policy. Quality management includes strategic planning, allocation of resources, and other systematic activities (e.g., planning, implementation, documentation, and assessment) pertaining to the quality system.
Quality management plan	A document that describes a quality system in terms of the organizational structure, policy and procedures, functional responsibilities of management and staff, lines of authority, and required interfaces for those planning, implementing, documenting, and assessing all activities conducted.
Quality system	A structured and documented management system describing the policies, objectives, principles, organizational authority, responsibilities, accountability, and implementation plan of an organization for ensuring quality in its work processes, products (items), and services. The quality system provides the framework for planning, implementing, documenting, and assessing work performed by the organization and for carrying out QA and QC.

or scientific-investigation plans (EPA 2001a), establishment of data-quality objectives (Barnard 1996; Wilson 1995), training and certification, quality-control activities, review of data (Edwards 2000), and assessment of data quality (Taylor 1996).

Although structured quality-assurance programs are a requirement for data collection in regulatory agencies, they are not currently a requirement for natural resource management agencies. Consequently, many regional ecosystem initiatives are still considering whether or not to establish structured quality-assurance systems based upon the expected benefits versus the potential costs. The author's recommendation has been to encourage the development of ecological quality-assurance programs (Lawrence and Palmer 1996) as the benefits outweigh the costs when properly conceived and implemented (Palmer and Mulder 1999).

Ecological Information Management Concepts

Ecological databases are often developed in regional ecosystem initiatives for the purpose of answering specific monitoring and assessment questions (Briggs and Su 1994). These databases need to have several attributes in order to achieve this goal. The data need to be of high quality. The correctness or integrity of these data needs to be maintained (Ingersoll et al. 1997). The data must be accessible, well documented, and easy to use (Brunt 2000) for the original intended objectives and must also be available to scientists with other planned objectives (Michener et al. 1997). The data must be secure for long periods of time (decades) even though computer hardware and software are likely to change frequently (Strebel et al. 1994).

The purpose of an information management system is to achieve the goals of fostering data defensibility, access, use, and permanence. As with a quality-assurance program, the information management system should be integrated with all phases of a project including planning, data collection, and data assessment. In fact, a very important role of information management in ecological monitoring programs is to facilitate quality-assurance activities. For example, electronic-data collection programs are often developed for monitoring programs to allow for quality-assurance checks to be undertaken at the time of data entry and thereby reduce the number field-data entry errors.

It is helpful to consider data management as a stepwise process (fig. 8-2). The first step is to plan the overall data management system, including data collection programs and the overall database design. Data is then acquired through field notes, portable data recorders, field data loggers, or laboratory analyses. Data are then entered into the database for processing.

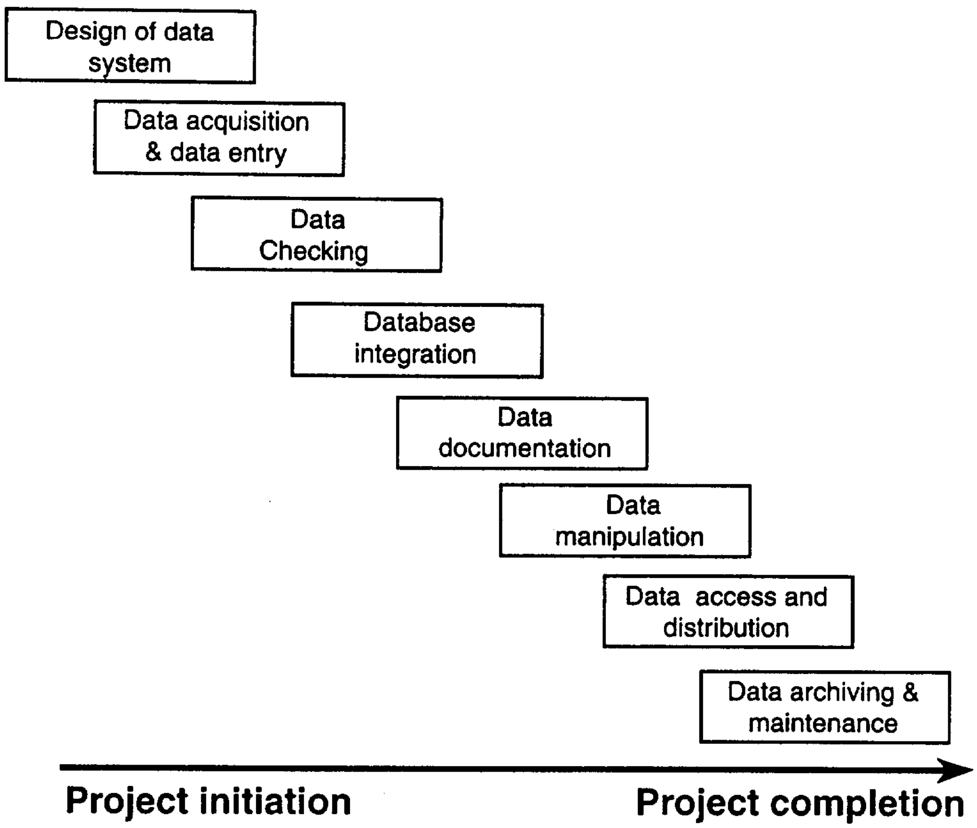

Figure 8-2. Steps in the data management process from project initiation through project completion.

An important first step is to identify data entry errors through quality-assurance checks (Edwards 2000) such as the evaluation of outlier values. The data are then integrated into the database with other data collected in the monitoring program at the same site or similar sites. Documentation of how the data were collected is developed and integrated with the original data as metadata. Data manipulation to summarize or collate the data can then take place, which improves the utility of the data. To encourage use of the data by others, data publishing can be undertaken. Centers that have been established to assist with the sharing of ecological data or data clearinghouses are notified of database content and accessibility. The data are then maintained through frequent backups to prevent loss or corruption. A process called data archiving is implemented to provide for the long-term preservation of the data, even after completion of the project. The resources required to undertake these activities are significant (Strebel et al. 1994), often requiring from 10 to 20 percent of the monitoring budget (Hale 1999).

The development of monitoring programs for regional ecosystem initiatives requires that some thought be given to the nature of the information management system that will be needed. In addition to maintaining the "internal" data collected within the program itself, it is important to note that data collected in other ongoing monitoring programs might be needed to effectively answer questions about the ecoregion and its management. For example, the national Forest Inventory and Analysis (FIA) program collects detailed information about all forests in the United States. The late-succession/old-growth forest module of the Northwest Forest Plan monitoring effort is planning to use portions of these data to evaluate status and trends in forests for the Pacific Northwest ecoregion. This is an example of a concept that is depicted in figure 8-3; required data to answer monitoring questions is shaded in gray. Some external programs such as FIA may provide data that is critical to the success of the regional ecosystem initiative; close ties will therefore need to be developed with these programs to ensure that these data are of high quality and are accessible. Other research or monitoring programs may also have data that are useful, and efforts will need to be taken to develop a data interface with these programs as well.

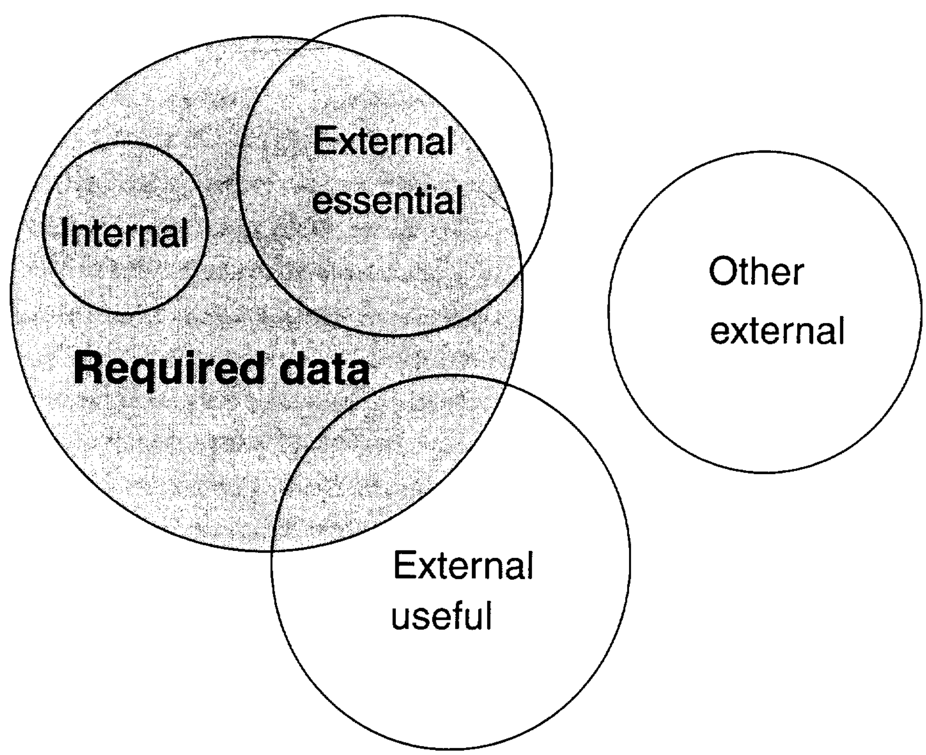

Figure 8-3. Sources of data for regional ecosystem monitoring programs. Data required to answer monitoring questions are shaded in gray. These data may come from internal or external programs. Close ties are needed to external programs providing essential or useful information to ensure high quality and accessible data.

Alternative Approaches to Quality Assurance and Information Management

There are a wide variety of approaches that can be taken to quality assurance and information management in regional ecosystem monitoring programs. The two extremes are the *craftsman-artisan approach* and the *formal programmatic approach* (Taylor 1987). The craftsman-artisan approach can be defined as one that depends on the use of highly competent scientists who can be trusted to provide high-quality data sets upon the completion of their project activities. Using this approach, overall quality is controlled through the peer review process and not through the implementation of a structured quality-assurance program.

A formal programmatic approach defines all the operational aspects that must be undertaken by participants in a monitoring program. These are defined in quality-assurance program plans and data management plans. The effectiveness of this approach depends on strict compliance to defined protocols implemented by competent staff. A support system of quality assurance and information management personnel provides assistance to ensure that data quality and data management goals are met.

When a monitoring program consists of many different complex investigations conducted by individual scientists in an independent manner, a craftsman-artisan approach might provide the most effective atmosphere to encourage excellence. When a large number of participants conduct similar measurements, a more formal approach is warranted. This is often the situation with regional ecosystem initiatives where many organizations and individuals are working together to achieve overall program goals. A common structured approach to quality assurance and information management serves to encourage the collection of comparable data that is of high quality and the documentation and sharing of these data in an efficient manner.

Recommendations for Regional Ecosystem Monitoring Programs

Without the establishment of some type of formal approach to quality assurance and information management, regional ecosystem monitoring programs by default select the craftsman-artisan approach. The selection of this approach puts these programs at the risk of many pitfalls associated with a lack of formalized planning of quality assurance and information management systems as detailed in table 8-3. Formal quality-assurance and information-management program development is needed to reduce this risk and improve the likelihood of being able to achieve high-quality data and information that are useful in adaptive management activities and have the characteristics of being long lived, accessible, and credible. These goals can be achieved by investing in the development and implementation of formal programmatic quality assurance and information management systems.

To start this process, a quality assurance program plan will need to be developed that addresses the factors identified in Table 8-1. An individual will need to be assigned to coordinate the development and implementation of this plan. Quality-assurance activities such as the development of quality-assurance project plans, training and certification of field crews, field audits, data checking, and data-quality assessments will need to be developed for each regional activity. Program participants will need to be trained in quality-assurance concepts to assist with the implementation of these plans. Adequate resources will also need to be allocated to allow for the successful implementation of the quality-assurance program.

In a similar manner, a structured data management system will need to be developed. This can be accomplished through a structured approach of information systems development that includes an analysis of the current information management situation, the definition of new requirements, the development of an information management system design to address these requirements, the programming and testing of the proposed system, the implementation of the system, and the evaluation and maintenance of the system over the long term. A data management plan is a document

Table 8-3. Some pitfalls associated with the lack of planning and execution of formal quality assurance and information management systems for regional ecosystem initiatives.

Pitfall	*Explanation*
Defensibility	Often there is no provision for the quality assurance of information gathered.
Access	Data access is often limited. Coordination among neighboring resource management units is restricted.
Use	Data are everywhere, but little of it is useful due to poor planning.
Permanence	Reporting and use of metadata will likely be limited leading to data entropy of newly collected data and rapid loss of legacy data.
Budgeting	Quality assurance and data management costs are often not included in project budget processes, making it difficult to implement or improve these systems later.

that incorporates the first three components of this approach. The data management plan should also answer specific questions related to the co-ordination and management of the data management system. A number of these questions are detailed in box 8-1. The data management plan must also consider and support quality assurance activities in addition to the other data management goals. These two documents can then serve as the framework for the development of monitoring activities within a regional ecosystem initiative.

Box 8-1. Questions to consider during the development of a data management plan for a regional ecosystem initiative.

1. Which interagency body oversees resolution of issues related to monitoring information management?
2. Should the information management system support only the monitoring program, or should related programs be integrated or linked?
3. Should such a system serve as a regional clearinghouse for monitoring information?
4. Should the system house and steward the data in a central location, or should these functions be distributed throughout the region?
5. What is the relationship of monitoring information management to existing agency data management systems?
6. Would the monitoring information network operate best as a metadata database, or should the data and metadata both be included in the regional system?
7. Can a basic level of support for monitoring information management (estimated to be 15–20 percent of the monitoring budget) be generated?
8. How can security and stability over time be assured in the face of institutional change?
9. What is the best way to incorporate valid legacy data into a monitoring information network?
10. How can a monitoring information system best deal with both the reality and notion of proprietary data?

Conclusion

Monitoring is a key component to the success of an adaptive process for natural resource management. Current approaches to quality assurance and information management in regional ecosystem monitoring programs are often informal and unstructured. It is recommended that a formalized structure be implemented for these programs to encourage data quality, access, utility, and permanence.

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